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Does Joystick Training Facilitate Relational Learning?

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Thirteen naïve capuchin monkeys (*Cebus [Sapajus] apella*) were manually tested with the transfer index (TI) procedure, a species-fair paradigm for assessing the capacity to learn and transfer learning. The animals were then trained to manipulate a joystick to control a cursor and to respond to stimuli on a computer screen. After the animals had mastered the remote cause-and-effect relations required by the computerized test system, they were returned to manual TI testing to determine whether the joystick-training intervention had affected the monkeys' capacity for efficient and relational learning. TI scores and overall accuracy were higher following the joystick intervention, but these differences were not statistically significant. Two-choice discrimination learning and reversal appeared to be associative in nature, and there was no evidence that joystick training made the monkeys more rule-like or relational in their learning. Despite the absence of significant differences, the patterns of results encourage further study of the ways that changes in the cognitive competencies of nonhuman animals might be catalyzed by significant learning experiences.

"The Language Research Center's Computerized Test System, initially developed for NASA, has proven to be revolutionary. It is used in dozens of laboratories here and abroad. It showed that chimpanzees can master, solely by observation, the skilled use of a joystick and thereby directional control of a cursor's movement on a monitor. Fortuitously, it proved to be an automation of the Wisconsin General Testing Apparatus. More importantly, it has allowed for a complete rewrite of the learning principles and abilities of the rhesus monkey and has enhanced comparative psychological inquiry with a wide variety of species – including humans." (Rumbaugh, 2013, p. 164).

Keywords: learning, intelligence, transfer index, monkeys

The history of comparative psychology is replete with apparatus innovations and new paradigms that have served to alter the field's understanding of animal cognition and behavior. For instance, the Wisconsin General Test Apparatus (WGTA; Harlow & Bromer, 1938) was instrumental in a large number of studies of animal learning and critical for demonstrating that macaques could "learn how to learn," or form learning sets (Harlow, 1949). The mark test of mirror self-recognition (Gallup, 1970), the stimulus-equivalence paradigm (Sidman, 1971), the cognitive mapping procedure (Tolman, 1948), and the uncertainty monitoring task (see Smith & Washburn, 2005) are just four examples of contributions that were informative in their own right, but that may be even more important because they served as catalysts for many further studies—for instance, studies of which species might "pass the tests" and which appear to fail to demonstrate particular competencies. What we understand about an animal's psychology is thus closely tied to and potentially changed by compelling methodological innovations.

In the 1980s, Rumbaugh and collaborators applied computer-game technology to the study and enrichment of nonhuman primates (Rumbaugh, Richardson, Washburn, Savage-Rumbaugh, & Hopkins, 1989; Savage-Rumbaugh, 1986), training chimpanzees and monkeys to respond to computer-generated stimuli by manipulating a joystick or using a touchscreen, in accordance to the rules of a variety of game-like tasks. Their

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first report that rhesus monkeys could master the discontiguous cause-and-effect relations required to control a computer-generated cursor by joystick manipulations (Rumbaugh et al., 1989) was itself somewhat revolutionary, as it showed that the monkeys could succeed on a type of challenge (i.e., learning under conditions of stimulus-response-reward discontiguity) that had been demonstrated as problematic for the species (e.g., McClearn & Harlow, 1954; Meyer, Polidora, & McConnell, 1961; Murphy & Miller, 1955; Stollnitz & Schrier, 1962). As was noted in the Rumbaugh (2013) quote at the beginning of the present manuscript, many other surprising findings have been produced with the computerized test system (elsewhere called the video-task paradigm, the psychomotor test system, and the Rumbaughx—pronounced "Rum-box" — to parallel other influential apparatus like the Skinner box, the puzzle box, the shuttle box, and so forth; see Washburn, Salamanca, Callery, & Whitham, 2017).

For example, rhesus monkeys have shown evidence of rule-like relational learning and positive transfer of learning, competencies that had previously been established only for apes (e.g., Washburn & Rumbaugh, 1991). Rhesus macaques and capuchin monkeys alike have learned symbols that represented the various computer tasks they knew, demonstrated reliable preferences among the tasks, chose from a menu to engage in tasks that they prefered, chose to have this opportunity to choose, and performed better on tasks they had chosen compared to the same tasks when assigned (Perdue, Evans, Washburn, Rumbaugh, & Beran, 2014; Washburn, Hopkins, & Rumbaugh, 1991). Both species have shown the capacity for prospective memory (Beran, Evans, Klein, & Einstein, 2012) and a wide range of judgments related to stimulus numerousness (e.g., Beran, Decker, Schwartz, & Shultz, 2011). They have demonstrated a large number of response-time phenomena, such as Stroop-like effects (Washburn, 1994) and functional cerebral asymmetries (Hopkins, Washburn, & Rumbaugh, 1990). Rhesus monkeys have evidenced use of both rule-based and information-integration modes of performance on categorization tasks and, in doing so, both demonstrated human-like cognitive competencies and furthered theories of human categorization performance (Smith et al., 2015). They also categorized dominance relations by observing videos of conspecifics in social interactions (Bovet & Washburn, 2003; Paxton et al., 2010). Macaques and capuchins have been shown to be susceptible to the same visual illusions manifest in (and previously documented only for) humans (e.g., Parrish, Brosnan, & Beran, 2015). These examples are a small sample of the ways in which our understanding of monkeys and their cognitive continuities (and discontinuities) with humans has been changed in the 30+ years that they have been "computer-game players."

It is certainly possible, even likely, that some of these findings would not have been obtained without use of the computerized test system. Some of the questions would have been impossible or impractical even to ask with a manual apparatus (e.g., Beran's 2008 study of enumeration and comparison of moving dots; target-prediction performance documented by Washburn & Rumbaugh, 1992). In cases like the emergence of relational learning (e.g., Washburn, Hopkins, & Rumbaugh, 1989; Washburn & Rumbaugh, 1991), the ease of controlling confounding cues, such as position or specific-stimulus effects and the efficient means for generating large numbers of trials (and thus, large amounts of experience) in a short period of time, may have facilitated the expression of previously unobserved competencies.

It is also an intriguing possibility that the monkeys themselves may have been changed by the joystick training. That is, it seems reasonable to suggest that the training required for monkeys to master the remote cause-and-effect relations associated with controlling a computer-generated cursor with a joystick also serves to sensitize the animals to other relational-learning opportunities, facilitating their subsequent learning. This indirect "learning-to-learn" effect might manifest itself in subsequent cognitive competences, each of which in turn provides scaffolding for the emergence of even more new mental aptitudes. The support for this hypothesis to date has been entirely speculative, correlational, and post-hoc; however, there are certainly examples in other literature for this kind of effect. Many researchers have reported that second-language acquisition is associated with generalized improvements in attention, executive functioning, and working memory (e.g., Bialystok, 2015; Bialystok, Poarch, Luo, & Craik, 2014; Crivello et al., 2016). And, some research suggests that playing video games may lead to enhancements in certain cognitive capacities, such as working memory (e.g., Granic, Lobel, & Engels, 2014), although more research is needed (Boot, Blakely, & Simons, 2011).

The present study was designed to test directly the hypothesis that mastery of cursor-control skills in the computerized-task paradigm has generalized effects on a monkey's ability to learn and to transfer learning adaptively. Comparative psychologists have been studying learning and transfer-of-training for decades, both for intrinsic reasons and also as possible measures of the intelligence of a species or an individual within a species (e.g., Bitterman, 1965; Mackintosh, 1965; Meador, Rumbaugh, Pate, & Bard, 1987; Meyer, Treichler, & Meyer, 1965; Rumbaugh & Gill, 1973). A significant advance in this research tradition was the transfer index (TI) paradigm, introduced by Rumbaugh as a way to control for individual and species differences in perceptual and motor processing, thus providing a species-fair test of learning and the capacity to use prior learning (Rumbaugh, 1969; Rumbaugh & Pate, 1984; see also Bonté, Kemp, & Fagot, 2014). The TI procedure is a variant on the two-choice discrimination-learning test that Harlow (1949) used to demonstrate learning sets, as discussed above. Animals are presented with a series of problems, each involving two novel stimuli; on each problem, they must learn through trial-and-error which stimulus is the S+ (the rewarded object) and which is the S- (the unrewarded object). In the TI paradigm, animals respond trial after trial on the same problem until performance reaches some accuracy criterion (typically either 67% or 84%), whereupon the reward cues are reversed without warning for 11 more trials. That is, the formerly rewarded stimulus becomes the S-, and the formerly unrewarded object becomes S+. The ratio of performance on these reversal trials (R%) to the level of accuracy on the pre-reversal, or acquisition trials (A%), is the transfer index: TI = A% / R%. Comparison of TI values across species has revealed systematic and reliable differences. Primates with large and complex brains tend to produce higher TI ratios, show positive transfer when the acquisition criterion is increased from 67% to 84% (i.e., more pre-reversal learning yields better reversal performance for apes and some monkeys, but poorer reversal performance by prosimians and smaller-brained monkeys), and evidence of relational rather than associative learning (Gibson, Rumbaugh, & Beran, 2001; Rumbaugh & Pate, 1984). Given that each animal's reversal performance is standardized against that same animal's baseline pre-reversal learning—so that every animal is brought to the same level of acquisition performance before cues are reversed—the TI value may be particularly useful as a quantitative and qualitative (i.e., indicator of whether learning is primarily stimulus-response associative or rule-like relational) measure of animal learning.

We hypothesized that mastery of cursor control through joystick manipulation would improve a monkey's ability to learn quickly and relationally and to transfer this learning when the stimulus cue values are reversed.

Method

Subjects

Testing this hypothesis requires naïve monkeys; fortunately, two new groups of capuchin monkeys (*Cebus [Sapajus] apella*) were obtained by the Language Research Center. The animals participated shortly after their arrival at the Language Research Center in fall of 2013 for Group 1, and spring of 2017 for Group 2. Although they may have been involved in behavioral research prior to their arrival, they had received no computer-task training and so were naïve with respect to the use of a joystick to respond to computer-generated stimuli. There were 8 capuchins in Group 1, 7 of which completed all phases of the study. There were 10 capuchins in Group 2, and 6 completed all phases of the study. Aside from some differences in the number of blocks per animal, the procedures were identical for the two groups. The monkeys lived in their respective social groups with indoor and outdoor access for the majority of each day but separated each day voluntarily into individual test cages where the TI testing and joystick training were conducted. Each monkey was randomly assigned to one of two sequences: Some animals completed 5 TI problems prior to joystick training, whereas the remaining monkeys completed 10 TI problems prior to beginning joystick training. Thus, the critical comparison for the present study was performance on Problems 6 through 10, prior to which half the monkeys had completed joystick training but the other half had not.

No monkey was deprived of food or water or reduced in body weight for purposes of testing. The animals earned nutritive rewards (Cheerios for TI testing, fruit-flavored chow pellets for the joystick tasks) for successful trial completion but were fully provisioned whether or not they participated in the research. Once the monkey voluntarily boxed in the test cage, it could engage in the task or rest at will.

Apparatus

TI testing. A hand-held version of the Wisconsin General Test Apparatus (WGTA; Harlow & Bromer, 1938) was constructed for these tests. Two foam panels (Owens-Corning Foamular moisture-resistant XPS insulation), each 25 cm × 25 cm, were combined as shown in Figure 1, so that rewards could be hidden in one of the two wells, with each well covered by a discriminative stimulus. By displacing the S+ stimulus, a monkey could retrieve the reward (a plain Cheerio); selection of the S- stimulus was unrewarded. A handle on the back of the WGTA made it possible to present the stimuli simultaneously to the monkeys without cuing the animal as to position of the reward, and to remove the apparatus after the first response so that the animal could not grab both stimuli. The experimenter was able, surreptitiously, to observe which stimulus was selected by the monkey from behind the vertical panel of the WGTA.

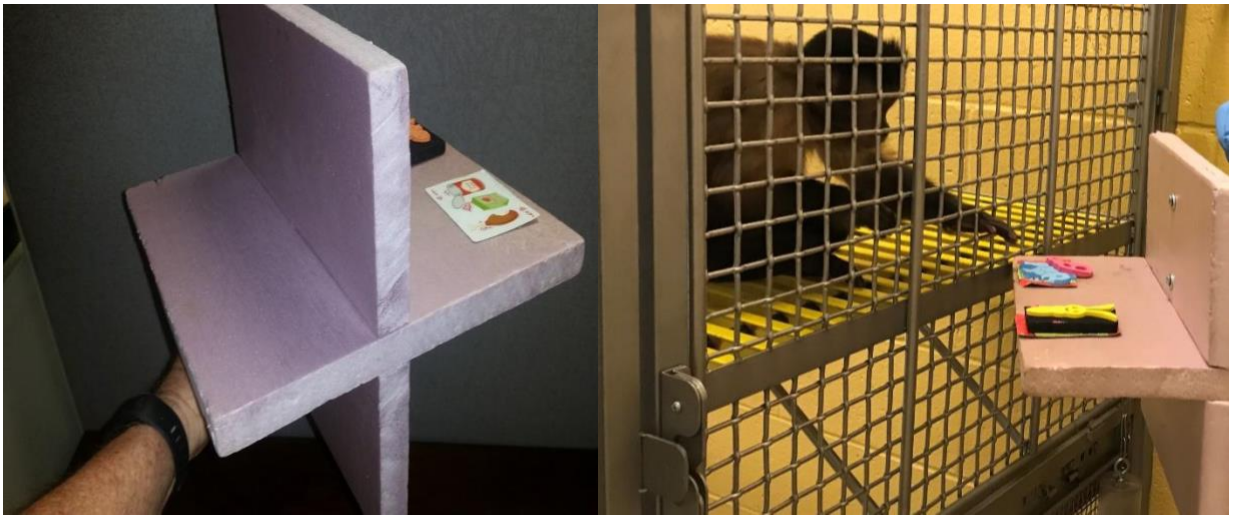

Figure 1. **(Left) The hand-held WGTA apparatus constructed for this study, and (Right) an illustration of how a monkey would respond to one of the stimuli that cover two small wells in the foam platform, in which a food reward can be concealed.** A handle allows the apparatus to be moved safely against the cage wall without biasing the monkeys with respect to position. The apparatus on the right has been pulled away from the test box for this photo.

Stimuli were constructed by using nontoxic glue to affix stickers, small toys, school supplies, and other arbitrary objects to standard playing cards. The cards served as the stimulus bases, covering the wells on the hand-held WGTA apparatus so the monkey could not see the location of the reward. Prior to the start of the study, the objects were paired randomly and one stimulus was labeled the S+ object (initially rewarded) whereas the other was labelled the S- (rewarded on reversal trials). These labels were written on the bottom of the cards so as not to be visible to the monkeys. Each pair of stimuli constituted one problem, and problems were selected randomly for each animal, with the constraint that monkeys should only be tested with novel problems (i.e., always two new stimuli for that monkey).

Randomized score sheets were generated to determine whether the S+ stimulus should be placed over the left or right well for all of the potential acquisition (pre-reversal) and reversal trials. Experimenters also used these score sheets to record whether responses were correct or incorrect.

Joystick training. The apparatus and software used for training capuchin monkeys on the computer-task paradigm are described in detail elsewhere (Evans, Beran, Chan, Klein, & Menzel, 2008; Leighty & Fragaszy, 2003). Each monkey could reach through the mesh of its individual test box to manipulate a joystick and to retrieve rewards (fruit-flavored chow pellets) while viewing stimuli on a computer monitor connected to a dedicated computerized test system mounted on a cart. The monkeys were trained on two joystick tasks for this study: SIDE and CHASE. The SIDE task requires monkeys to bring the joystick-controlled cursor into contact with a stationary target wall on the screen. The cursor began each trial in the middle of the screen. Initially, all four borders of the screen were target walls, so that the targets completely surrounded the cursor. Deflection of the joystick handle resulted in isomorphic cursor movements, eventually bringing the cursor into contact with a target wall, resulting in the delivery of a pellet. Efficient trial completion automatically increased the difficulty of subsequent trials: four walls became three walls, then two walls, then one full wall, then one partial wall, and finally a small rectangle located on a single border of the screen. Long response times titrated the task to easier levels. When a monkey reached criterion on the SIDE task (i.e., 5 consecutive trials at each target size, with a response time of less than 5 s each), the target stimulus began to move on the screen (CHASE task). Each monkey had to use the joystick to catch a circle that moved at 45-degree angles on the screen whenever the cursor moved and remained stationary when the cursor stopped. The criterion for CHASE was 20 consecutive trials at each target size, with a response time of less than 10 s each.

Procedure

TI testing. Each monkey voluntarily entered its test box, and the door was closed behind the animal to prevent interference and to minimize distraction from cage mates. The experimenter selected a pair of stimuli at random and, after checking to ensure that the monkey had not previously attempted a problem with those stimuli, administered TI trials until the monkey reached the acquisition criterion or completed 22 trials without attaining criterion. Criterion levels were taken from Rumbaugh and Pate (1984), and their use is standard in the literature (De Lillo & Visalberghi, 1994). However, whereas Rumbaugh and colleagues discarded any problem in which the animals scored below or above the 67% or 84% criterion, we retained all problems in which the monkeys achieved a level of 67% or greater. Thus, a monkey reached the acquisition criterion for a problem if it was correct on at least 7 of Trials 2 to 12 (Trial 1 of the acquisition and reversal blocks are always discarded and not counted in the computation of TI because the monkey cannot possibly know the correct choice yet), 9 correct by Trial 15, 10 correct by Trial 17, 12 correct by Trial 20, or 14 correct by Trial 22. If the monkey reached criterion, it immediately received 11 reversal trials (again, with Trial 1 ignored as it must be given to cue the reversal).

On each trial, the experimenter checked the scoring sheet to see which well of the handheld WGTA should be baited with a single Cheerio. The well was baited out of sight of the monkey and then both wells were covered with stimuli, with the S+ object over the reward. The WGTA was then presented to the monkey, taking care to move the apparatus toward the test box so that the monkey was between the two wells so as not to bias the animal toward one or the other position. The monkey reached through the mesh of the test box to displace one of the two stimuli. If the response was correct, the monkey was allowed to retrieve the reward from the well; if the response was incorrect, the apparatus was removed immediately so the monkey could not reach for the second stimulus object. The monkey's response was recorded on the score sheet, and the next trial was set for the monkey. The sequence of acquisition trials for the monkey to reach criterion plus the reversal trials constituted one completed problem. For the Group 1 monkeys, the animals either completed 5 problems prior to joystick training and 5 problems after mastering the SIDE and CHASE tasks (Condition 1), or completed 10 problems prior to joystick training and another 5 problems following SIDE and CHASE (Condition 2). The conditions were similar for the Group 2 animals: Condition 1 animals completed 5 TI problems, then joystick training, then 10 TI problems; Condition 2 animals completed 10 TI problems, then joystick training, then 5 TI problems.

Joystick training. As detailed above, monkeys were tested in enclosed boxes separated from their cage mates. A dedicated test station was then positioned so the monkey could reach the joystick and pellet cup. The SIDE or CHASE task was administered, using the parameters described by Evans et al. (2008). Performance was examined at the end of each day to see whether the monkey had reached criterion. Each SIDE session began in the easiest condition and titrated automatically based on the monkey's performance. When a monkey reached the SIDE criterion and could efficiently move the cursor into contact with the single small wall, the animal was moved to the CHASE task. CHASE sessions began with a short block of SIDE trials, allowing the animal to "warm up" by moving through each difficulty level, before advancing automatically to the moving target of the CHASE task.

Results

TI values [R% (Trials 2-11) / A% (excluding Trial 1)] were computed for each problem. Given that some stimulus pairs might be easier to learn or to reverse than others for purely random and individual reasons (e.g., a monkey might be particularly attracted to a particular object that was designated as the S+), five-problem means were calculated for each monkey. Across monkeys and problem blocks, TI performance averaged 0.47 before joystick training and 0.62 after joystick training (standard deviation = 0.17 for both conditions). To control for sequence effects (i.e., number of problems completed), introduction of joystick training was staggered across monkeys, as described in the procedure. The results of these manipulations are depicted in Figure 2.

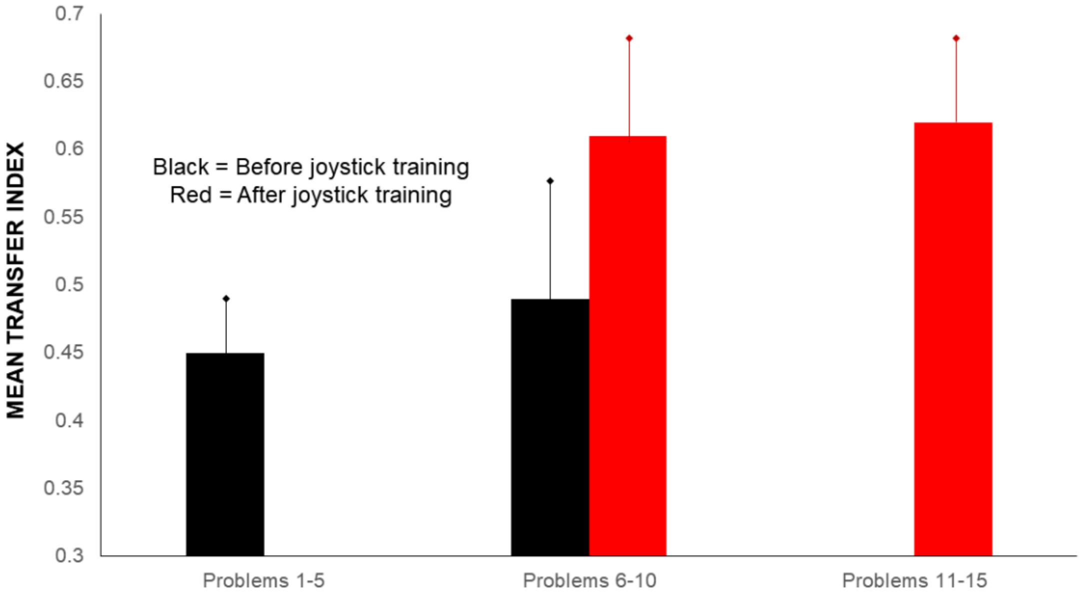

Figure 2. **Mean TI scores (with standard errors) as a function of problem block and joystick-training condition.**

TI scores generally increased across blocks of problems, as would be expected, and appears to benefit particularly from intervention of joystick training; however, analysis of variance, correlation analyses, and Wilcoxon signed-rank test statistics showed that neither the effect of problem block nor joystick condition was significant (*p*s > 0.10), given the small sample and high variability (see Table 1 for TI values by animal, problem, and condition). Although the monkeys that performed Problems 6 to 10 following joystick training produced TI ratios that were almost 25% higher than the animals that entered joystick training after Problem 10 (TI = 0.61 vs. 0.49, respectively), those same animals also produced higher TI values on Problems 1 to 5 (0.51 vs. 0.41, respectively), which were all pre-joystick training. This outcome was despite random assignment of monkeys to the training and testing orders. Overall, the increase in performance between problem blocks that were separated by joystick training (mean TI increase = 16%) did not differ significantly from the increase between blocks without joystick experience (mean TI increase = 11%).

Table 1

Transfer Index Values for Problems Before and After Joystick Training, by Animal

Group 1 Problem	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Bailey	.49	.69	.32	.40	.28	.79	.79	.94	.61	.31	1.10	.69	.94	.79	.94
Bias	.48	.47	0.0	.55	0.0	.79	.47	.28	.63	.94	.44	.49	.14	.11	.14
Gonzo	.93	.61	.83	.28	.12	.80	1.41	.33	0.0	1.24					
Gretel	.55	.31	0.0	.10	.11	.22	.37	.41	0.0	.32	.63	.95	.83	.47	1.26
Mango	.55	.63	.94	.31	.95	.60	.41	.32	.49	.55					
Mason	.16	.69	.63	.24	.32	1.24	.79	.37	.55	.82					
Star	.99	.30	.28	1.26	.40	.79	.31	.14	0.0	.20	.70	.10	.83	1.12	.14
Group 2 Problem	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Albert	.77	.93	.73	.11	.20	.31	1.09	.16	.55	.14	.69	.16	.63	.69	.64
Ira	.83	.28	0.0	.14	.49	.33	.55	.22	.55	.63					
Irene	.12	.77	.47	.78	.37	1.10	.55	.33	.79	1.10					
Ivory	.10	.63	0.0	.30	.12	.63	.37	.79	1.43	.96	.48	.32	.96	.32	.44
Lychee	.16	.79	.79	.55	.40	.41	.41	.12	.69	.66					
Paddy	.37	.49	.31	.55	.79	.32	.79	0.0	0.0	.24	.61	1.41	.66	.69	.24

Note. White cells = problems before joystick training. Shaded cells = problems after joystick training

Complicating this picture is the fact that observed pre-reversal performance also varied across these problems, so that some of these TI values reflect the 67% criterion, but others reflect higher (even 100%) acquisition levels, and the number of problems was not evenly distributed across criterion levels for the two joystick-training conditions. Figure 3 illustrates this complication from the data obtained here.

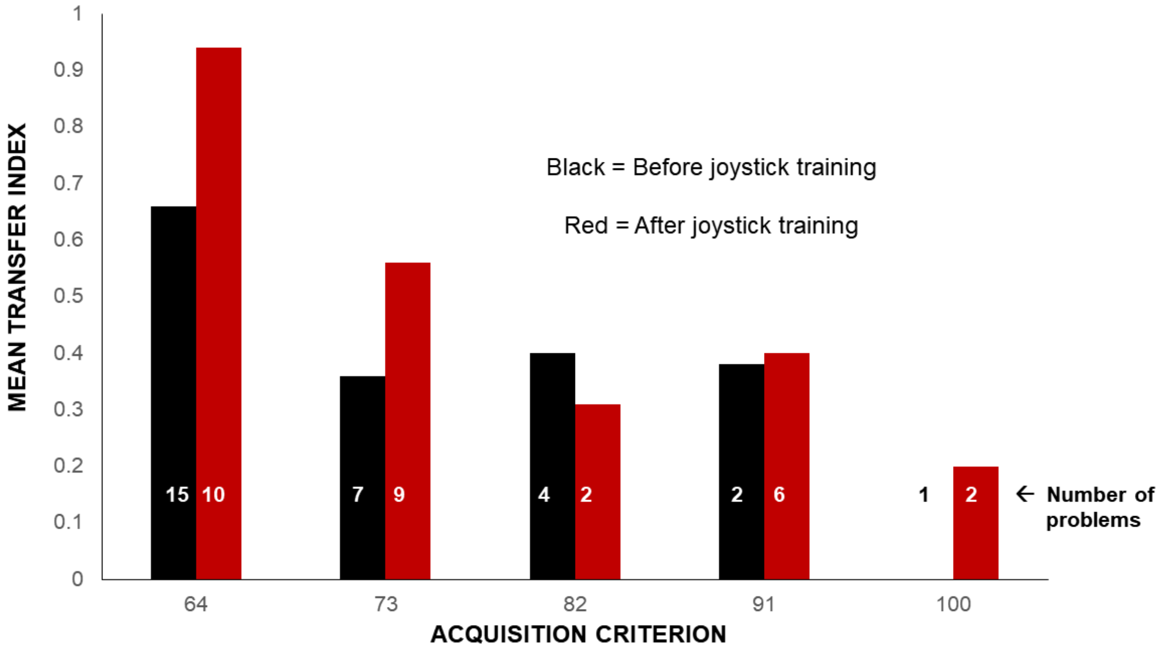

Figure 3. **Mean TI score as a function of percentage correct in acquisition trials and of joystick-training conditions**. The numbers in the bars indicate the number of problems completed in each condition.

Two conclusions are apparent from this Figure 3. First, there was no evidence of positive transfer of learning (Rumbaugh & Pate, 1984) or improvement in TI scores as one increased the criterion level for acquisition. Whether the problems were administered before or after joystick training, it seems generally true that the better the monkeys did during acquisition, the worse they performed during reversal. This observation is further confirmed by the negative correlations between acquisition and reversal performance, $r(11) = -0.28$ before joystick training and -0.34 after; $ps > 0.10$ for both coefficients and for the difference between them (using r to z transformation).

The second conclusion that is evident from this figure pertains to the difficulty of comparing pre-joystick and post-joystick TI with acquisition criterion allowed to vary, as was done here. For example, the TI value of 0.40 reflects much better overall performance and much more impressive reversal performance in particular for the six post-joystick problems (A% = 91) than for the four pre-joystick problems at A% = 82. Thus, the overall (nonsignificantly) increased TI values following joystick training compared to before (0.62 vs. 0.47, respectively) occurred even though there were fewer problems at the easiest criterion level. To unpack this potential confound, we also analyzed the effects of joystick training on overall accuracy level on the TI task, that is, on the percentage of correct responses in the acquisition and reversal trials combined (rather than the ratio of the two). Overall, accuracy averaged 55% on TI problems that preceded joystick training and 56% on problems that followed, reflecting the fact that reversal performance averaged 34% prior to joystick training and 44% in TI problems after joystick training. The effects of problem block and joystick condition are depicted in Figure 4.

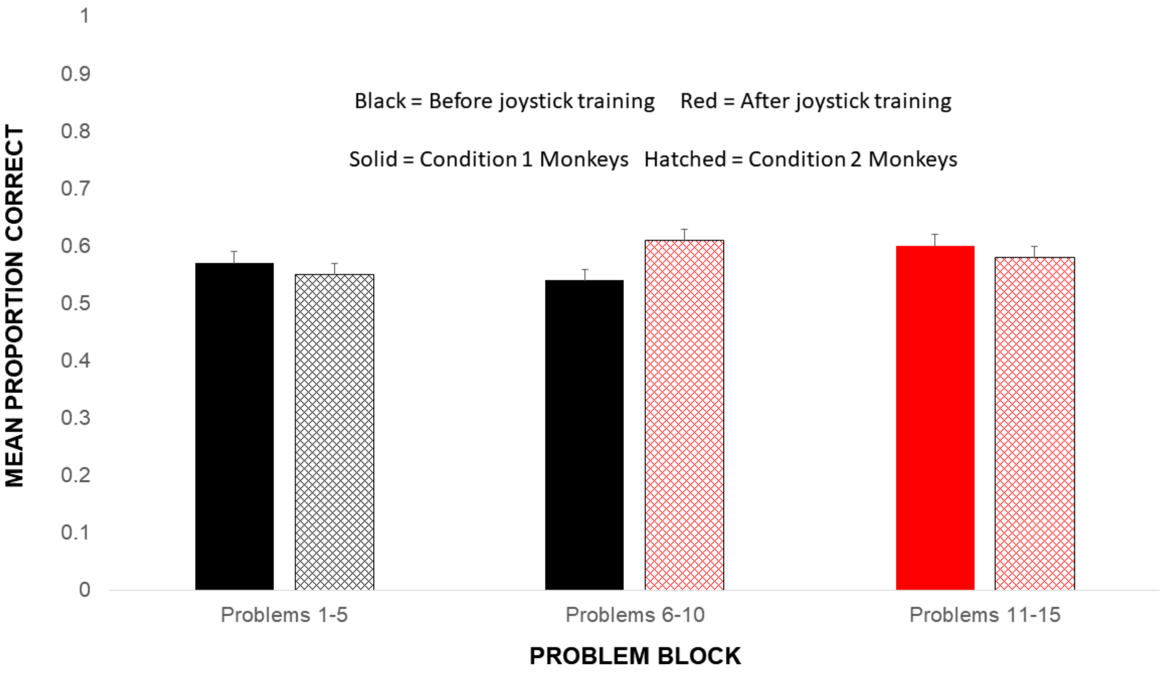

Figure 4. **Mean overall accuracy (and standard error of the means) as a function of problem block and joystick-training**

As was reported in the analysis of TI values above, neither problem block nor joystick training conditions had a significant effect on accuracy ($ps > .10$), according to analysis of variance and z-tests. Unlike that previous analysis though, overall accuracy showed no hint of improvement as a function of problem block alone. Across monkeys, overall accuracy increased by about 7% between TI problem-blocks that were separated by joystick training. In contrast, accuracy declined slightly and nonsignificantly between consecutive TI problem blocks that did include intervening joystick training.

Discussion

Experience can alter an organism's cognitive competencies. This belief is the foundation of our education of children, a motivation behind the appeal of a liberal arts education, and the rationale behind "cognitive training" programs that purport to produce generalized benefits in attention, memory, executive functioning, or other cognitive abilities. The present investigation was designed to determine whether the psychomotor training that enables a naïve monkey to become a computer user would also produce improvements in a markedly different type of learning: two-choice discrimination learning and reversal. That is, would a monkey's performance on the TI task be changed after mastering the remote cause-and-effect relations required to control a computerized cursor by manipulating a joystick?

The 13 capuchin monkeys tested here achieved performance criteria on the SIDE and CHASE computerized tasks and can now use a joystick to respond to a variety of computer-generated stimuli in accordance with the demands of a wide range of cognitive tests. They also completed 15 manual TI problems per animal, producing values that were within the range reported elsewhere for capuchin monkeys (DeLillo & Visalberghi, 1994). The present monkeys averaged a TI = 0.77 at the 67% acquisition level (which included actual acquisition values between 63% and 67% accuracy) and TI = 0.37 for the six problems we obtained at A% = 84%; by comparison, DeLillo and Visalberghi reported a TI range of 0.49 to 0.76 at A% = 67% and a range of 0.46 to 0.67 at A% = 84%. Note that the present monkeys, like the capuchins studied earlier, produced a decline in TI as the A% criterion became more stringent. Rumbaugh and Pate (1984) described this as negative transfer, one indication of stimulus-response associative rather than rule-like relational learning. Thus, the capuchin monkeys continued to perform the TI task in a way that was qualitatively similar to prosimians, baboons, and some macaques, but qualitatively different from humans, chimpanzees, and other macaques (Bonté et al., 2014; Rumbaugh & Pate, 1984; Washburn et al., 1989). There was no evidence that a joystick-training intervention had an effect on the relational versus associative learning in this paradigm.

Similarly, there were no statistically significant effects to suggest that joystick training produced generalized improvements in two-choice discrimination-learning accuracy or TI value. However, the patterns of means reported here are more intriguing than these nonsignificant comparisons would indicate. Without suggesting at all that the evidence is stronger than it is, the absolute improvements in TI performance after joystick training encourage further investigation of this hypothesis. Any generalized improvements in learning-and-transfer that come from basic cursor-control Rumbaughx training, if such effects exist at all, seem likely to be small. In particular, the present analyses of response accuracy raise the possibility that the current study may have been underpowered to detect modest improvements as statistically reliable.

Given these findings, it seems clear that further investigation should either include additional animals, additional joystick training between TI problem blocks, additional TI problems to promote stability, or all three procedural improvements. Another potentially important point is consideration of specific other things that could be learned with joystick tasks, such as matching-to-sample, that may affect the way monkey "conceptualize" tasks and, therefore, contribute to subsequent TI performance. The small sample and other design decisions are important limitations of the current opportunistic study. That acknowledged, the present study reflects almost five years of data collection. Because the acquisition of naïve monkeys is a rare event in our laboratory, it is a unique set of circumstances that permits the investigation reported here. Whereas we would welcome the chance to test additional naïve monkeys on TI before and after training them to use the joystick on computer tasks so as to address some limitations of the present research, we also believe that these data represent an important and informative first attempt to address the issue of how monkeys' cognitive competencies may be changed by computer-task training.

This question—and the parallel question about how chimpanzees' cognitive competencies were altered by computer-based experience—were foundational to the research program that distinguished Duane Rumbaugh's career. He often examined this topic, from his early-career investigations of the long-term behavioral effects of enriched or impoverished development (e.g., Davenport, Rogers & Rumbaugh, 1973) to his career-retrospective writings (Rumbaugh, 2013; Rumbaugh & Washburn, 2003) on comparative cognition. The Language Research Center that Rumbaugh founded and that supported the investigation reported here was initially established to study chimpanzees' capacity to learn, use, and understand a computer-based language; subsequently, Rumbaugh and his colleagues focused on what chimpanzees could accomplish cognitively after language training, without which they could not have accomplished. Additional research is needed to understand more fully how experience and learning serves to scaffold and catalyze future psychological competencies—to answer not just “Can nonhuman animals learn X?” but also “Having learned X, what additional cognitive heights can the animals attain?” Answering such questions requires commitment to long-term support and study of a colony of resident animals that participate in research across their lifespans, and is greatly facilitated by methodological innovations like the Rumbaughx that provide for versatile, efficient, and potentially enriching cognitive testing.

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